Distribution of diatoms in the northern Kimberley region, Western Australia in relation to water chemistry

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Abstract

118 diatom taxa from 31 genera were identified from 18 sites in the mid-northern Kimberley region of Western Australia. 12 taxa (10% of the total) are recorded for the first time in Australia. Diatom taxa were clustered into groups using Euclidean distance metric analyses. 17 species (14% of the total) occur over a wide span of total dissolved solids (within the range of 30-42 000 mg/L), nitrate levels (0.4-7.8 mg/L) and pH regimes (5.3-8.4). 92 species (78%) are distributed in discontinuous groups at sites ranked along TDS gradients. *Navicula radiosa* and *N. pupula* were the most widespread.

Introduction

There have been relatively few surveys of diatoms from inland waters on the Australian continent (Thomas 1983). Those regions which have been examined for diatoms include the coastal regions of Victoria, New South Wales, and Queensland (Foged 1978), a variety of water bodies in Tasmania, Victoria, and South Australia (Tudor 1973), and the Magela Creek system (Brady 1983) and Alligator River Region (Thomas 1983) of the Northern Territory. John (1983b) prepared an extensive survey on the diatom flora of the Swan River Estuary near Perth, Western Australia, and has conducted a number of detailed studies with light and electron microscopy on diatom species collected from the Swan and Canning Rivers, and nearby regions around Perth (John 1980, 1981a, 1981b, 1981c, 1982a, 1982b, 1983a, 1983b, 1986).

To date there have been no published surveys of diatoms in the Kimberley region in the northwestern part of Western Australia. John (1982b), however, did report on the morphological variation of *Cymbella sumatrensis* in collections from Lake Argyle, Western Australia.

The Kimberley region represents a relatively isolated region on the Australian continent and may provide a distinct diatom flora from that previously reported in Australia. We present a survey of the diatoms found in several creeks and large rivers in the mid-northern Kimberley region. These systems contain waters with a wide range of total dissolved solids (TDS) and dissolved nutrients.

Study Site and Methods

The study area was located on the Gardner Plateau (600 m) within 150 km of Drysdale River National Park in the Kimberley region of Western Australia (Fig. 1). The Kimberley region is considered to have a dry, monsoonal climate and to undergo extreme seasonal variability in annual rainfall with the wet season occurring during December to March (Forbes and Kenneally 1986). The annual mean precipitation for the northern Kimberley is 800-1 000 mm. This study was conducted at the end of the dry season during August 1981 and the creeks and rivers contained little water. Many of the smaller rivers and creeks were merely isolated water holes whilst the larger rivers, although still flowing, had water levels well below the wet season peak.

Benthic diatoms and water samples were collected by E R Tudor from the 18 locations listed in Fig. 1. Water temperature and pH were measured at each sampling site. Nitrate-nitrogen was measured by the cadmium reduction procedure, ortho-phosphate by the molybdate method, and total dissolved solids (TDS) by evaporating a known volume of filtered water sample to dryness at 100°C and weighing the residue (APHA 1976).

Diatom frustules were cleared of organic matter in concentrated H_2SO_4. Two 1 mL aliquots of the cleaned diatom material from each sample were dried and mounted in Hyrax on cleaned glass slides. At least 500 frustules were counted from each sample to determine the

relative frequency of each taxon. The permanent diatom slides used in this study are housed at Northern Arizona University, Flagstaff, AZ, USA, and the original samples are held by E R Tudor.

The diatom taxa (identified by DWB) were clustered (by DMC) from a computer database (Paradox) used to generate an analog table of presence-absence data [1 or 0 for each species and each site]. The report facility of the data base was then used for the two-way sorting of Table 1 which was printed using Word5 with Postscript. The clustering process, based on presence-absence data (not relative percentage frequency), gave equal weight to each species recorded from each site. From the range of linkages tested (using the program SYSTAT), the Euclidean distance metric analyses with complete linkage to furthest neighbour was selected for final grouping. Green, Carmone, & Smith (1989) discuss this linkage in a recent review of clustering methods.

Nineteen groups of species with the most similar range of occurrence were arranged in a non-hierarchical sequence of groups to show the nature of the gradient (whether continuous or discontinuous) when the sites were arranged in columns from the least to the highest concentration of TDS (Table 1).

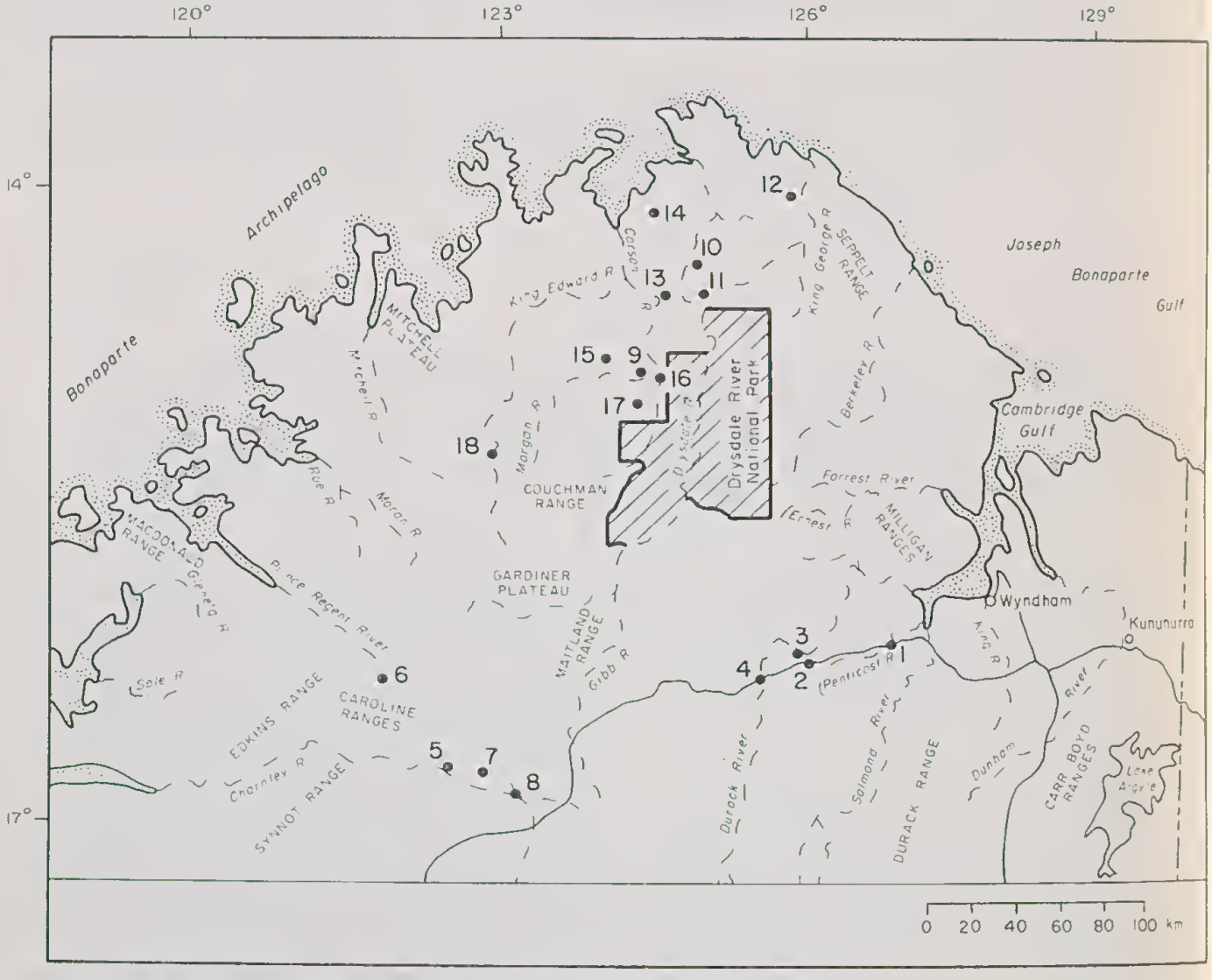

Figure 1 Map indicating the 18 collection sites in the North Kimberley region, Western Australia. Sites 1-18 indicated. 1. Pentecost River; rocks in residual pools. 2. Residual pool in Palmer Creek with dense plant growth; used by livestock. 3. Residual pool close to Durack River; abundant water lilies. 4. Residual pool in Durack River. 5. Deep residual pool at Magpie Springs; dense growth of filamentous algae. 6. Creek between Mount Jameson and Mount Agnes. 7. Tributary of Drysdale River; pool with slow flow and dense aquatic plant growth. 8. Hann River; water flowing; sandy with dense aquatic plant growth; used by livestock. 9. Morgan River; sandy substrate; used by livestock. 10. Tributary of Drysdale River; small residual pool; rocky substrate; abundant filamentous algae; used by livestock. 11. Redidual pool in dry creek bed near Drysdale River; *Pandanus* palms growing close to creek; used by livestock. 12. Residual pool in tributary of King George River; abundant growth of water lily; used by livestock. 13. Carson River; slow flowing water through shallow pools. 14. Residual pool in creek south of Pago Mission; sandy and rocky substrate. 15. Residual pool in creek between Theda and Old Theda Station. 16. Residual pool in Carson River at crossing close to Old Theda Station. 17. McDonald Creek; residual pool; rocky substrate. 18. King Edward River; rocky substrate; water lily in pools and *Pandanus* palms adjacent to river.

Table 1

Diatom species from northern Kimberley region, Western Australia. Species grouped by Euclidean distance metric with complete linkage to furthest neighbours.

			New Aust. Record	Locality Number (Sites ranked, from lowest to highest Total Dissolved Solids)																
				9	17	7	3	2	8	15	16	18	4	6	5	12	14	11	13	10	1
SITE CHARACTERISTICS																					
TDS	Total Dissolved Solids	mg/L		30	40	40	80	90	100	110	110	170	200	210	250	250	370	370	460	660	42000
NO_3-N	Nitrogen	mg/L		<0.4	<0.4	<0.4	1.3	3.3	<0.4	2.4	1.3	<0.4	1.3	1.4	<0.4	<0.4	<0.4	1.3	0.4	7.8	1.9
O-P^5O_4	Phosphate	mg/L		0.03	0.11	0.09	0.04	0.16	0.06	0.94	0.18	0.42	0.05	0.03	0.06	0.07	0.03	0.02	0.05	0.20	0.22
pH	Acidity			7.3	6.5	5.3	6.6	6.4	6.7	7.5	7.5	7.2	6.7	7.4	6.9	5.9	6.2	7.2	8.4	7.4	7.6
L/Stn	Livestock use. Near old station/mission			L				L	L	Stn	Stn					L	M	L		L	
DIATOM TAXA (percentage frequency; * < 1%)																					
Group 1																					
Nitzschia palea (Kutz.) W. Sm.					7	4.2	6.2	5.6	8	5	4.5	9.6	2.4	5.8	64.2	23	*	*	*	8	
Gomphonema gracile Ehr. Emend. V.H.					*	*	3.8	6.2	2	1.6	*	1.6	4.8			*		6.2	24	2	
Achnanthes minutissima Kutz.					11.4	13	27.2	*		8.6	9		39.6	4		10	*	16	27	1.8	
Achnanthes microcephala (Kutz.) Grun.					*	1.8	*	*		*	*		*	*		1.2	*	*	*	6	
Navicula cuspidata (Kutz.) Kutz.				1.8		*	1.8	1.6		*	*		*	*			*	4	3	*	
Nitzschia kuetzingiana Cl.				*	*			5.8	*	1.6			*		*	8	*		*	4	
Stauroneis phoenicenteron (Nitz.) Ehr.				*				7.4	*		*	1.8	1.8	*		*	1.2	*		*	
Navicula radiosa Kutz.				48	11.6		10.8		55	10	4.5	13	12.4	65.8	3	1.8		30.2	4.2	24	*
Navicula pupula Kutz.				*			11.8	10.2	*	1.6	*		5	*		*		1.8		*	*
Group 2																					
Navicula cryptocephala Kutz.				1.8	27.6				1.8	11.6	9	*			*			18.2		25.6	
Synedra ulna (Nitz.) Ehr.				2	3.7		*		*	*	*	4.8		2	*					*	
Cymbella sumatrensis Hust.				*	*		*					*			*			*	*	*	
Achnanthes exigua Grun.				*					*	*	*			*				*		*	
Cyclotella stelligera Cl. & Grun.				*		*	1.6			*	4.5			*	*		*			2	
Neidium affine (Ehr.) Pfitz.							*	*	*	5	*			*	*					*	
Pinnularia braunii var. amphicephala (A.Mayer ex Hust.) Patr.				*		4.6			*		*	4.8	*	2.4		2.6	*	*	2		
Cymbella cymbiformis var. *nonpunctata* Font.		+		4.2	8					*	*	49.6		*				4.2	6.2	6.2	
Group 3																					
Hantzschia amphioxys (Nitz.) Ehr.				*				*				*	7.8					*	*	*	
Gomphonema parvulum (Kutz.) Kutz.								17.2	7.8			*	6.2						4.8		
Melosira granulata (Ehr.) Ralfs				*			12.2			*	4.5	*	2.4					*	16.4		
Group 4																					
Cymbella minuta var. *silesiaca* (Bleisch ex Rabh.)				*			4.4			*		*			*	*				*	
Eunotia flexuosa Brab. ex Kutz.							*	*				*				4.2					
Eunotia camelus Ehr.				7.6		25.8	*	13.8				1.4	2.2			3					
Surirella linearis W. Sm.				*			*					*	*							**	
Stenopterobia intermedia Lewis				4.8	1.2		*		9.2				*								
Surirella tenera Greg.				*							*			*							
Nitzschia fonticola Grun.				4				*		18.3											
Nitzschia filiformis W. Sm.				*																	

Table 1—*continued*

Diatom species from northern Kimberley region, Western Australia. Species grouped by Euclidean distance metric with complete linkage to furthest neighbours.

	New Aust. Record	Locality Number (Sites ranked, from lowest to highest Total Dissolved Solids)																	
		9	17	7	3	2	8	15	16	18	4	6	5	12	14	11	13	10	1
Group 5																			
Surirella linearis var. *constricta* Grun.				2															
Eunotia formica Ehr.				*															
Nitzschia gracilis Hantz.			60	2.8								*							
Navicula subrhynchocephala Hust.				2								*							
Group 6																			
Melosira italica (Ehr.) Kutz.		6.4			*														
Frustulia rhomboides (Ehr.) DeT.					.1														
Nitzschia lorensiana var. *subtilis* Grun.					*														
Stenopterobia intermedia var. *subacuta* Fricke					*														
Group 7																			
Navicula subatomoides Hust.							*							*					
Opephora martyi Herlb							*												
Navicula pupula var. *rectangularis* (Greg.) Grun.							*												
Navicula mutica var. *cohnii* (Hilse) Grun.							*												
Eunotia tenella (Grun.) Cl.				14.2			*												
Eunotia incisa W. Sm. *ex* Greg.	+			2.4			*												
Navicula radiosa var. *parva* Wallace	+						2.4		*	6									*
Group 8																			
Synedra radians Kutz.	+							1.6	*								*	*	
Surirella robusta Ehr.								*											
Nitzschia vexans Grun. in V.H.	+							3.2											
Mastogloia elliptica var. *dansei* (Thwaites) Cl.								3.2											
Epithemia turgida (Ehr.) Kutz.								*											
Epithemia adnata (Kutz.) Breb.								8.3											
Amphora ovalis var. *affinis* (Kutz.) V.H. ex Det.								1.6	*										
Group 9																			
Gomphonema subclavatum var. *commutatum* (Grun) A. Mayer	+									*									
Neidium gracile Hust.										1.2									
Nitzschia vermicularis (Kutz.) Grun.					*					*									
Group 10																			
Eunotia pectinalis var *undulata* (Ralfs.) Rabh..				10	*	*				*		*							
Pinnularia biceps Greg.					2	*						*	*						
Cymbella bengalensis Grun.	*											*							
Navicula muticoides Hust.												*							
Hantzschia virgata (Roper) Grun.												*							
Rhopalodia gibba var. *ventricosa* (Kutz.) H.& P. Perag.												*	*						
Rhopalodia gibba (Ehr.) O. Muell.												*	*						
Hantzschia amphioxys var. *capitata* O. Mull.							4.8					*							
Gyrosigma spencerii (Quek.) Griff. & Henfr.					*			*				*							
Anomoeneis sphaerophora (Ehr.) Pfitz.								1.6				5.8						*	

Group 11																	
Cymbella turgida (Greg.) Cl.					*						*						
Cyclotella meneghiniana Kutz.											*						
Navicula pupula var. *capitata* Skv. & Meyer											2						
Nitzschia linearis W. Sm.											20.8						
Group 12																	
Eunotia pectinalis var. *minor* (Kutz.) Rabh..			6.8	10.8	*			1.6				1.6	1.2				
Stauroneis anceps f. *gracilis* Rabh.			*				*										
Navicula accomoda Hust.			*						*								
Caloneis bacillum (Grun.) Cl.													*				
Stauroneis kriegeri Patr.													*				
Frustulia rhomboides var. *saxonica* (Rabh.) DeT.													6.2				
Navicula subtilissima Cl.			*										13.8				
Anomoeneis serians var. *brachysira* (Brab.ex Kutz.) Cl			*										70.8			*	
Group 13																	
Neidium affine var. *amphirhynchus* (Ehr.) Cl.										2							
Achnanthes exigua var. *heterovalva* Krasske										*							
Navicula halophila (Grun.) Cleve									*	*				*			
Hantzschia elongata (Hantz.) Grun.	+													*			
Fragilaria construens var. *venter* (Ehr.) Grun.														*			
Eunotia pectinalis (O.F. Mull?) Rabh..														2			
Amphora ovalis (Kutz.) Kutz.														*			
Caloneis ventricosa var. *minuta* (Grun.) Patr.	+									*				*			
Group 14																	
Eunotia naegelii Migula	+		74.4			19						33					
Pinnularia brevicostata Cl.						1.6						3.6					
Eunotia diodon Ehr.	+			7.8	*	7						1.8		3.8			
Stauroneis phoenicenteron var. *braunii* (Perog. & Herib) Voight	+				*	*								*			
Cymbella lanceolata (Ehr.) van Heurck					*									*			
Surirella biseriata Breb.												*		1.8			
Neidium iridis var. *amphigomphus* (Ehr.) A. Meyer						*								2			
Hantzschia amphioxys var. *vivax* (Hantz.) Grun.						*						*		*			
Stauroneis phoenicenteron f. *gracilis* (Ehr.) Hust.	+					*								*		*	
Pinnularia borealis Ehr.						*											
Neidium hustedtii Krasske						*											
Navicula mutica Kutz.					*	*											
Group 15																	
Eunotia curvata (Kutz.) Lagerst.												4.2			*		
Coconeis placentula var. *euglypta* (Ehr.) Cl.			3												*		
Anomoeneis serians (Breb. ex Kutz.) Cl.			*												*		
Amphora veneta Kutz.															1.8		
Rhopalodia gibberula var. *vanheurckii* O. Muell.	+	2													3.2		
Group 16																	
Nitzschia intermedia Hantz.																2	
Pinnularia mesolepta (Ehr.) W. Sm.					*											*	
Pinnularia obscura Krasske					*											*	
Rhopalodia gibberula (Ehr.) O. Muell.																*	*
Group 17																	
Coconeis placentula var. *lineata* (Ehr.) V.H.									*		*				*		
Rhizosolenia eriensis Smith								*			*		*		*		*
Nitzschia punctata W. Sm.															*		*
Entomoneis paludosa (W. Sm.) Reim.															*		1.2
Amphora coffeiformis (Ag.) Kutz.															*		19.6

Table 1—*continued*

Diatom species from northern Kimberley region, Western Australia. Species grouped by Euclidean distance metric with complete linkage to furthest neighbours.

	New Aust. Record	Locality Number (Sites ranked, from lowest to highest Total Dissolved Solids)																	
		9	17	7	3	2	8	15	16	18	4	6	5	12	14	11	13	10	1
Group 18																			*
Nitzschia frustulum (Kutz.) Grun.					*			3.2	*	*									*
Thalassiosira lacustris (Grun.) Hasle																			1.2
Diploneis suborbicularis (Greg.) Cl.								*											2.8
Diploneis oblongella (Naeg. ex Kutz.)			*																2.8
Nitzschia granulata Grun.																			3.2
Nitzschia sigma (Kutz.) W. Sm.																			5.8
Navicula henfleri var. *leptocephala* (Breb.ex Grum) Patr.	+																		10.2
Pleurosigma elongatum W. Sm.																			15.6
Amphora acutiuscula Kutz.																			32.4
Rhoplodia musculus (Kutz.) O. Muell.																			
Group 19																			
Achnanthes lanceolata var. *dubia* Grun.						*			*			*							
Pinnularia abaujensis var. *subundulata* (A.Mayer ex Hust.) Patr.	+					*						*							

Results and Discussion

One hundred and eighteen diatom taxa from 31 genera were identified from 18 collection sites in the Kimberley region of Western Australia (Table 1). Water temperatures at the various sites ranged from 20°C to 30°C.

Pennate diatoms were the most common with taxa in the Naviculaceae and Nitzschiaceae making up 54% of the flora. The 12 taxa designated "+" in Table 1 have not been reported in other major regional diatom floras for continental Australia (Foged 1978, Brady 1983, John 1983b, Thomas 1983).

Navicula radiosa showed the widest distribution of all species collected in the region by occurring in 83% of the sites (mean relative abundance = 16.4%; s.e.± 4.7) at TDS values ranging from 30 to 42 000 mg/L, and pH values ranging from 5.9 to 8.4. *Navicula pupula* showed a similar distribution across a wide range of TDS and pH, but occurred in only 67% of the sites with an average relative abundance of <4.0.

The diatom floras are most clearly divided between those in freshwater sites with TDS <660 mg/L and those (Group 18) in the single highly saline sample with TDS of 42 000 mg/L. Few diatom species (mostly in groups 16 and 17) span this division within the TDS range from 460-42 000 mg/L.

Amphora acutiuscula, *A. coffeiformis*, *Entomoneis paludosa* and species of *Pleurosigma* are frequently associated with waters of high salinity in western USA and Canada (Czarnecki & Blinn 1977, 1978, Felix & Rushforth 1979, Tuchman & Blinn 1979, Czarnecki *et al.* 1981, Hammer *et al.* 1983, Kaczmarska and Rushforth 1983). John (1983b) also found *Amphora coffeiformis* and a new variety of *Pleurosigma* (*P. elongatum* var. *grosse punctatum*) in habitats with high salinity in the Swan River estuary system near Perth, Western Australia.

Twenty species (Groups 1,2 and 3 in Table 1) are distributed over a wide range of dissolved solids from 30 to 660 mg/L. Most species however cluster into groups that are characteristic of intermediate ranges, with a few species within the group occurring discontinuously over a wide range of total dissolved solids.

Eunotia spp. tend to dominate the diatom floras (i.e. their relative frequency becomes greater than 40-50% of the diatom population) in the Kimberley sites when the water has a TDS less than 250 mg/L, a pH lower than 6.5 and nitrate lower than 3.3 mg/L. These findings are in agreement with Patrick and Reimer (1966) and Lowe (1974) for North American taxa and reports on the distribution of Eunotia in Australia (Foged 1978, Brady 1983, John 1983b, Thomas 1983).

Stenopterobia intermedia also frequently occurred in sites with low pH and low TDS, but the relative abundance was low (mean = 1.0%; s.e.± 0.5).

Water with the lowest TDS of 30 mg/L appears to be colonized by species with a wide ranging TDS tolerance rather than by species that are confined to low salinity. Those species which occur in the wide range of TDS also occur in the full range of nitrogen. The response to nitrogen is not correlated with TDS.

Species in groups 8 and 16 are found in water with higher (1.3-7.8 mg/L) nitrate levels. Species in groups 13 and 19 are characteristic of intermediate (>0.4-3.3 mg/L) nitrate levels and species in groups 5, 7, 11, 12 and 15 occur at lower (≤0.4 mg/L) nitrate levels.

The response to pH is less marked than that of nitrogen or TDS. Most species occur in waters with pH ranging widely from 5.2-7.3. Species in group 14 however occur mainly within the pH range 5.3-7.2. Those species in group 18 tend to occur in the pH range of 7.5-7.6. While those species in group 17 are characteristic of the highest pH range 7.6-8.4. Response to phosphate gradient is least apparent.

Table 1 provides a general impression of the ecology of the diatom flora from open water in the Kimberley region. About 20% of the species occur more or less continuously over a wide geographic range of freshwater containing 0-660 mg/L TDS. The remaining 80% of the species are found discontinuously at sites of similar TDS or nitrate levels. This suggests an opportunistic colonization of any site by 12 groups of diatoms that tend to be associated, if they occur at all.

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